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ATLANTIC HURRICANE SEASON OF 1970

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ABSTRACT

A general overview of the 1970 hurricane season in the North Atlantic is presented together with detailed accounts of all named tropical cyclones and certain subtropical or hybrid storms.

1. GENERAL SUMMARY

The 1970 hurricane season, in some respects similar to that of 1968, produced very few named storms in the Atlantic but a bumper crop in the eastern Pacific. However, the opportunity for tropical storm development in terms of the number of seedling disturbances that crossed the tropical Atlantic differed little over the past 3 yr. In 1969, it will be recalled, there was an abundance of hurricanes in the Atlantic but fewer than normal in the eastern Pacific.

Of the seven named Atlantic storms of 1970, only three reached hurricane intensity; and only Celia brought hurricane-force winds to the United States. These figures compare with a total of 180 tropical storms and hurricanes over the past two decades for a yearly average of nine. Of these, an average of three per year crossed the U.S. coastline, and three every 2 yr brought hurricane winds to the mainland.

Nevertheless, 1970 will be remembered as the year of Celia, the most destructive storm ever to reach the Texas coast. Celia distinguished herself in a number of other ways, although falling short of the size or intensity of Carla (1961) or Beulah (1967). Only a minuscule portion of the $453.8 million of damage attributed to Celia resulted from coastal flooding and storm surge. The greatest damage was apparently caused by wind gusts rather than sustained winds, which occurred predominantly in the left semicircle and to the rear of the storm center rather than in the right semicircle as is normally the case. Had Celia crossed the coastline about 25 mi farther south, the damage would have been mainly due to storm surge; and it probably would not have been a record-breaking storm.

A notable feature of the 1970 season was the general lack of tropical storm activity in the middle and eastern Atlantic. An inspection of monthly 700-millibar-height anomaly patterns showed that, during the middle of the season, when activity in this area is normally at a maximum, the middle-level ridge was displaced somewhat farther south than normal with no well-developed area of negative anomalies over the Tropics. Thus there was no broad zone of deep easterlies established to provide a favorable environment for the African seedling disturbances that emerged from the coast during this fertile period. To the contrary, such disturbances would tend to be deflected southward toward the equatorial trough, and disturbances orginating in the intertropical convergence zone (ITCZ) would be inhibited from breaking off and migrating northward.

During the 1970 season, for the first time the Air Force and Navy reconnaissance aircraft flew standard profile tracks across the four quadrants of each tropical storm and transmitted profile data of temperature, pressure, and wind. This system is an important innovation for the hurricane warning service: it ushers in an era in which hurricane dynamic climatology will be systematically developed and will provide the forecaster the means of assessing the structural and energetic character of the hurricane vortex and for applying real-time dynamic reasoning in developing his forecast, using systematic procedures and decision trees for reducing prediction errors and optimizing warning measures.

Forecast errors during the 1970 season were notably small. The average displacement error for all 24-hr forecasts was only 76 n.mi., whereas longer term averages are more than 50 percent greater. The corresponding average displacement error for the 1969 season was 135 n.mi. It should be noted, however, that most of the storms of the past season moved slowly along relatively smooth, straight persistent tracks (fig. 1). This always contributes toward better verification scores.

2. INDIVIDUAL NAMED STORMS

HURRICANE ALMA, MAY 17–27

Alma sustained hurricane intensity for a brief period during the daylight hours of May 20 to become only the third May hurricane of record and the second of this century. None of the hurricanes directly affected the United States, but there were three tropical storms in May that crossed the Louisiana or Florida Gulf Coast.

A weak depression formed in the southwest Caribbean Sea on May 17 and gradually became better organized as it moved northward. Rapid deepening occurred during the night of the 19th; and by midday on the 20th, the system reached what proved to be its maximum intensity when a Navy reconnaissance flight found a central pressure of 993 mb (29.32 in.) and 70-kt winds.

The deepening took place in response to favorable environmental conditions including low tropospheric shear in the vicinity of the storm, a strong upper level jet in the outflow region, and apparent low-level inflow from the east. However, as increasing westerly shear disrupted the storm's circulation and thermal pattern, it weakened

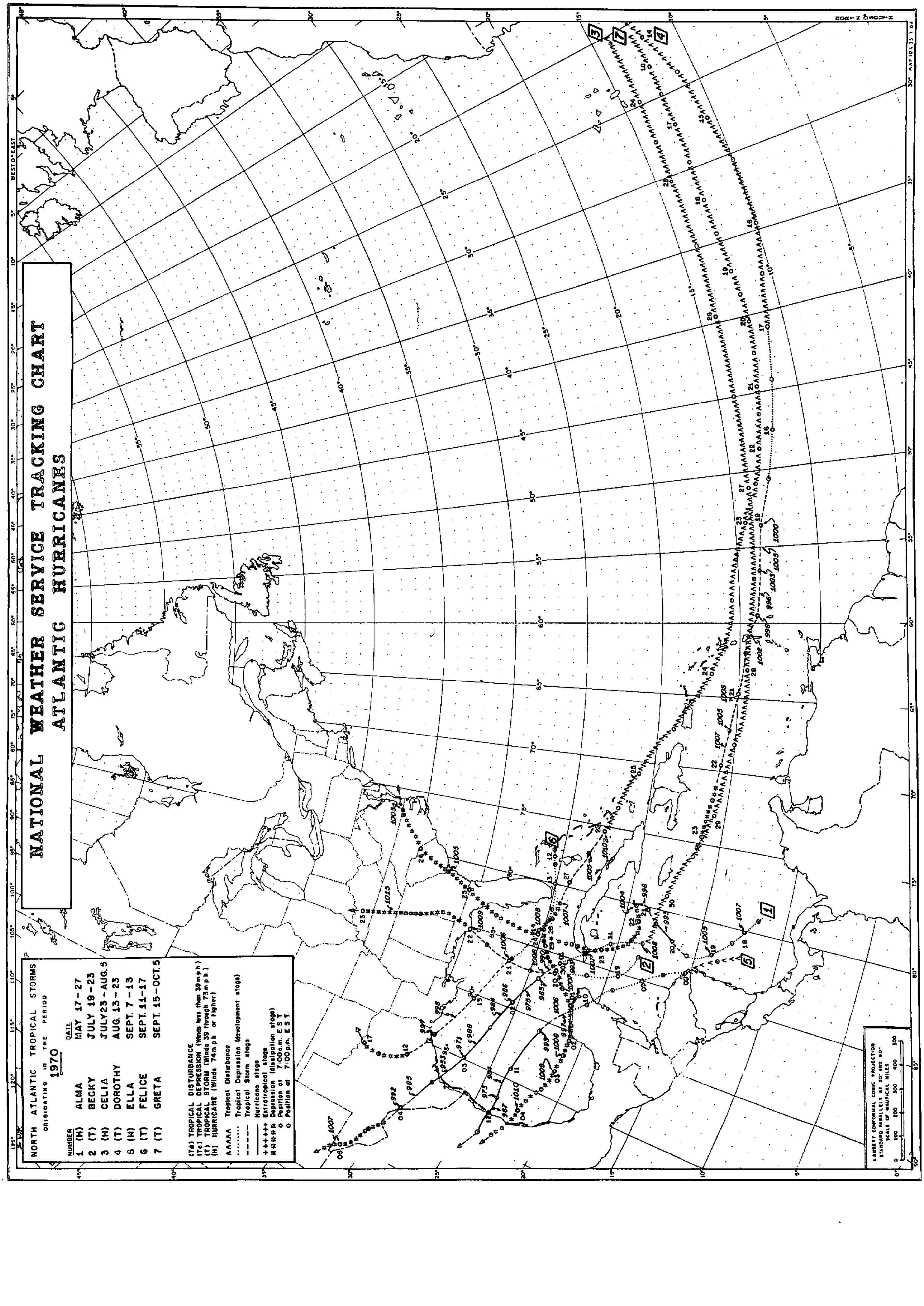

FIGURE 1.—Atlantic hurricanes and tropical storms of 1970.

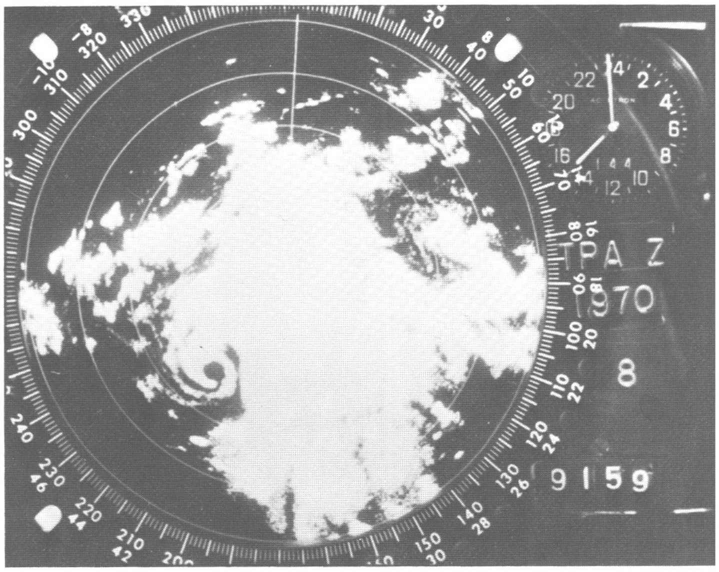

FIGURE 2.—Tropical depression remnants of hurricane Alma as seen by Tampa radar at 1500 GMT on May 24, 1970.

rapidly. Alma dropped below hurricane intensity by the evening of May 20 and weakened to a tropical depression on the following day. Alma thus proved to be short-lived, maintaining storm intensity for less than 48 hr. During this period, however, heavy rains in advance of the northeastward-moving center spread over central and eastern Cuba, causing flash floods in which seven persons perished.

The residual depression hesitated south of Cuba for a day before crossing the western part of the island on a northward track that ultimately carried it across the upper West Coast of Florida and northeastward along the coastal sections of the South Atlantic States where it was finally absorbed by an advancing cold front. As the depression passed west of Tampa, radar revealed a remarkably well-formed spiral band structure and the appearance of an eye (fig. 2). However, available data, consisting mainly of peripheral ship reports, indicate that the central pressure at the time was no lower than about 1008 mb (29.77 in.) and highest winds were only about 30 kt in squalls east of the center which illustrates the fact, well known to the forecasters, that a radar eye is not a sufficient condition for the existence of a hurricane. The extensive rain shield to the east spread much-needed rains over central and south Florida that had been plagued by an extended dry spell.

TROPICAL STORM BECKY, JULY 19–23

Two events contributed to the development of the season's second named tropical cyclone. The main impulse was provided by a massive rain system that surged northward from the ITCZ near Panama on July 16. By July 18, this zone of convection dominated a broad area between Swan Island and western Cuba. Here, it was joined by a lower tropospheric vorticity maximum that had passed through the Lesser Antilles on July 16.

The resulting depression provided NHC (National Hurricane Center) forecasters with their first opportunity to study the evolution of a tropical cyclone with the aid of time-lapse movies of ATS (applications technology satellite) photographs in real time. Although pressures were not unusually low, these movie loops revealed a trend toward better organization of the convective cloud system as the depression moved through the Yucatan Channel. A reconnaissance flight found 50-kt winds around a 1011-mb (29.85-in.) pressure center on July 20, and tropical storm Becky was named.

As Becky moved into the eastern Gulf of Mexico, a fairly strong low-level circulation had developed; but warming of the central core was still insufficient to form an eye and produce large pressure falls at the surface. On the evening of July 20, a ship (call sign LGHM) reported a pressure of 1002.5 mb (29.60 in.); and later, the SS *Socony Vaccuum* (KIGL) sustained winds of 55 kt. The morning reconnaissance flight reported the incipient formation of a wall cloud. Radars at Tampa and New Orleans also spotted the developing eye. Indications were that Becky had become a minimal hurricane with estimated surface winds of 65 kt; and in view of the impending threat to the Florida Panhandle, hurricane warnings were issued for the coast from Fort Walton to Port St. Joe, with gale warnings and a hurricane watch elsewhere from Mobile to St. Marks.

The attempt, however, at eye formation proved to be abortive. It is not uncommon in a tropical storm for one or more of the spiral bands to temporarily wrap itself into an apparent eye that fails to persist. This probably was the case with Becky, as well as in Alma as the latter approached the Florida coast. While it is not possible to state definitively why Becky did not become a true hurricane, one may, in retrospect, enumerate some unfavorable aspects of the vortex and its environment, including unfavorable thickness values, northerly wind shear to the west, and mid-tropospheric ventilation that may have disrupted the temperature gradient of the storm.

As the storm continued northward, it slowly deteriorated. Hurricane warnings were discontinued before Becky crossed the coast near Port St. Joe after daybreak on July 22. The lowest reported pressure at landfall was 1007 mb (29.74 in.) at the Cape San Blas Coast Guard Station. Gale-force winds in squalls and tides up to 6 ft (about 3 ft above normal) occurred from Apalachicola to St. Marks. A tornado destroyed a house and severely damaged three others near the town of Panacea, Fla., on the coast south-southwest of Tallahassee.

Becky weakened rapidly as it moved inland, but a low pressure area accompanied by heavy rains was tracked northward into Kentucky. The only serious flooding appears to have been confined to the Tallahassee area where over 8 in. of rain fell. The Red Cross reported that a total of 104 families suffered some loss due to rising

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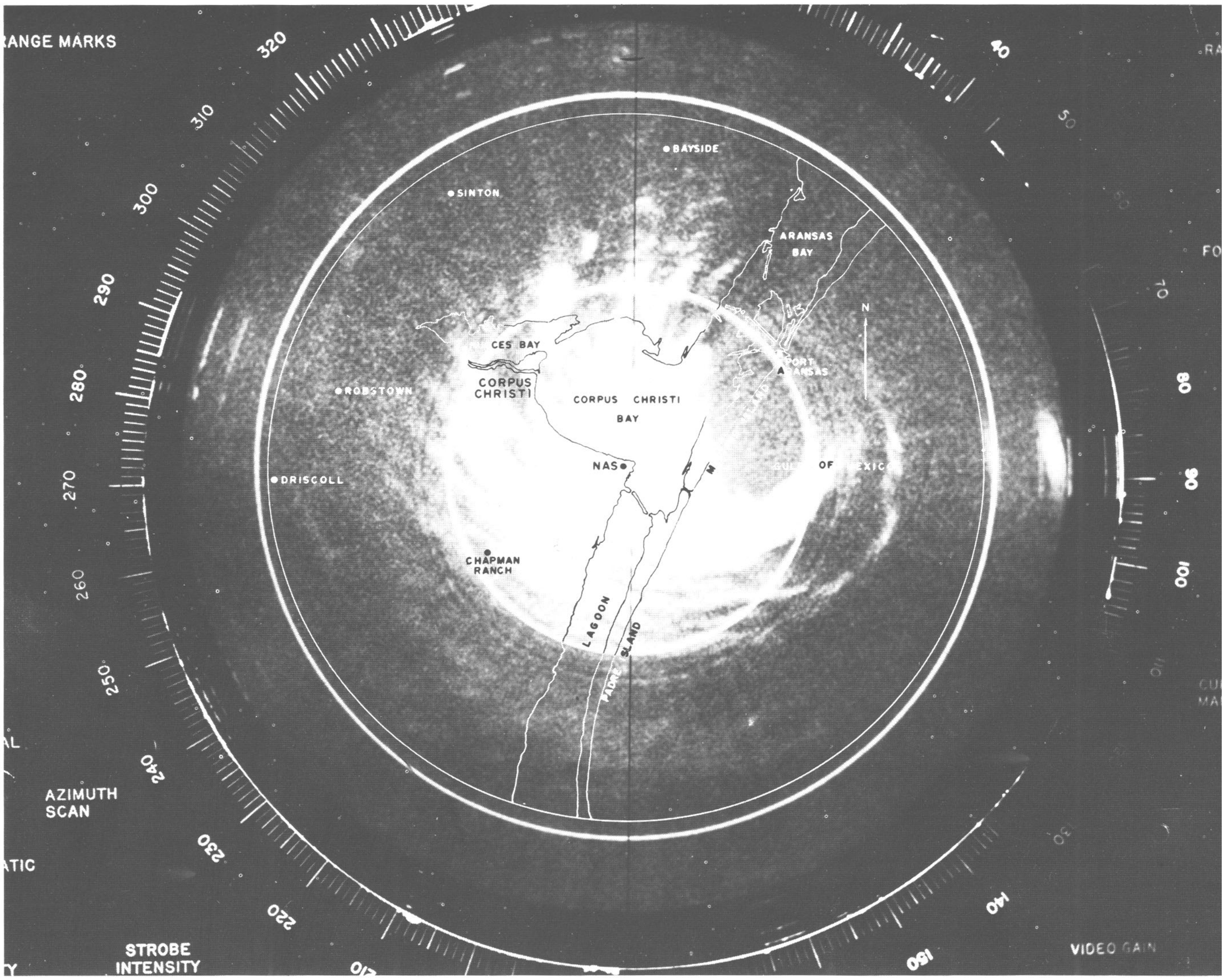

FIGURE 3.—Hurricane Celia approaching Corpus Christi Bay as seen by radar at Corpus Christi Naval Air Station at 2020 GMT, on Aug. 3, 1970 (Official U.S. Navy photograph).

water in this area. Farther north, the rains proved beneficial in relieving extremely dry conditions in Georgia and Alabama.

The lowest pressure, 1002.5 mb (29.60 in.), was recorded by the afore-mentioned ship (call sign LGHM) at 7:00 p.m. EDT on July 20, and the highest sustained winds were 55 kt reported by the SS *Socony Vaccuum* at 5:00 a.m. EDT on July 21.

HURRICANE CELIA, JULY 23–AUGUST 5

Celia formed in the northwest Caribbean Sea from a seedling disturbance that moved off the African Continent on July 23. On this day, the 10,000-ft winds at Dakar, averaging 40 kt, shifted in a manner characteristic of the passage of a tropical wave. The disturbance moved rapidly across the open tropical Atlantic, reaching the Lesser Antilles in only 5 days. In the Caribbean, however, the trade-wind environment was less vigorous; and the tropical wave, after entering the Caribbean on the 28th, did not reach the vicinity of the Cayman Islands until the 30th, where a closed wind circulation around a low-pressure center developed.

On the 31st, a reconnaissance plane reported a radar "eye" visible near the west coast of the Isle of Pines; however, due to the proximity of land, the aircraft was unable to penetrate and determine the intensity. During the evening of the 31st, the depression crossed the extreme western tip of Cuba near Cape San Antonio that recorded a minimum pressure of 1007 mb (29.74 in.). Winds gusted to 40–45 kt over a broad area including western Cuba, the Isle of Pines, and the Cayman Islands. Although winds and storm-surge action were of little significance as the depression crossed Cuba, five persons died, four drowning in flash floods and one electrocuted by a downed powerline.

As the tropical cyclone emerged over warm water in the Gulf of Mexico and a rich vein of moisture began to feed into the vortex from the Caribbean through the Yucatan Channel, pressures began to fall rapidly; and the characteristic mass circulation of a hurricane was quickly established. Early on August 1, an Air Force plane found that the central pressure had fallen to 993 mb (29.32 in.) with sustained winds of 70 kt in the boundary layer. During the day, ATS 3 photographs revealed that a pronounced feeder band had formed, emanating from the Caribbean through the Yucatan Channel into the vortex, reminiscent of the situation during the rapid deepening of Camille in 1969. In a period of less than 8 hr, the central pressure fell from 990 mb (29.24 in.) to 965 mb (28.50 in.) at 2344 GMT on August 1. During the night, the feeder band migrated westward with the storm system and moved over the Yucatan Peninsula. During this time, the central pressure rose, even though other environmental factors seemed to favor the maintenance of intensity of the storm.

By early morning on August 3, with the storm only 250 mi off the Texas coast, the central pressure had risen to 988 mb (29.18 in.); and sustained winds, measured by Doppler radar, had diminished from a maximum value of 103 to 75 kt. At this time, the pressure again began falling, and the vortex continued to intensify until after it crossed the coast just north of Corpus Christi. At the point of landfall, the minimum sea-level pressure recorded by a land station was 945 mb (27.90 in.), a total drop of 43 mb in approximately 15 hr, 26 mb of which occurred in 9 hr.

Circulation analyses of the August 2, 0000 GMT data revealed very little basis (at the time) for the second fall in pressure. After daylight on August 2, however, the ATS 3 movie loops began to show two significant developments that were probably related to the second intensification. First was the reformation of a strong feeder band, this time emanating from Tehuantepec and the Gulf of Campeche, spiraling northward into the hurricane vortex. The other was evidence of accelerated outflow to the west and north of the hurricane center, implying an increase in solenoidal circulation in this region. Diagnostically, these two factors may be either independent or complimentary. The latter, while reflecting an increased mass circulation, does not speak explicitly to the reason for this increase. The former bears evidence of the northward movement of air from the rich moisture source along a trajectory that optimizes the stretching of vertical columns and a trend toward saturation of a deep layer of air entering the hurricane vortex, thus giving a richer fuel source for the system.

The fluctuations in central pressure of this storm led the forecaster to a more conservative assessment of the maximum winds in the hurricane than postanalyses indicated. Not until a second dropsonde was released on the morning of August 3, which verified a continued downward trend in central pressure, did the advices reflect an increase in predicted sustained winds from 90 to 115 mi/hr.

It is interesting to note that an Air Force plane flying at 700 mb recorded central pressure values of 970 mb (28.64 in.) and 963 mb (28.44 in.) at 1153 and 1303 GMT, respectively, while maximum flight-level winds were only 70 kt. In this instance, the increase in mass circulation, as in the case of such storms as Cleo (1964), occurred in the lowest few thousand feet and was not reflected as high as the 700-mb level. However, during the penetration at 1856 GMT, the Air Force reconnaissance flight reported a central pressure of 953 mb (28.14 in.) with maximum winds at the surface and at flight level of 120 kt.

FIGURE 4.—Hurricane Celia damage at the Corpus Christi International Airport (Official National Ocean Survey Photograph).

Sometimes, when a hurricane is intensifying and its circulation is not in a quasi-steady state, the isotach maximum, which normally occurs in the right-front quadrant, apparently tends to migrate cyclonically around the vortex center at a conserved radius (Blumen and LaSeur 1958). In such instances, renewed development is usually reflected through an increase in mass circulation observed in the lower few thousand feet. The maximum convection in the eye wall rotates with the isotach maximum, and the eye wall sometimes breaks open in those quadrants that are normally the strongest in steady-state hurricanes. This was the case with Celia. Figure 3 shows a radar picture of the eye of the storm as it moved into Corpus Christi Bay. To the north, there was a break in the eye wall; and very little rain fell. South of the hurricane center, in the region of heaviest convection, spectacular damage occurred from a cluster of high-energy winds of short duration that raked across the residential and business areas of the city from west to east within a period of less than 0.5 hr. Residents who were interviewed said that the structures in which they were located trembled under the strain of sustained winds of 70 to 80 mi/hr for some minutes before the great burst of winds struck and produced, almost instantaneously, the major damage attributed to the storm. At the Corpus Christi Weather Service Office at the airport, sustained winds of 70 to 80 mi/hr had been observed for several minutes prior to the great burst that sent the wind speed up to 161 mi/hr for several seconds after which it returned to the previous sustained value. During this short period,

TABLE 1.—*Tropical cyclone data for hurricane Celia on July 30–August 5, 1970* [*courtesy of EDS* (*Environmental Data Service*), *NOAA*]

Station	Date	Pressure (inches)		Wind (miles per hour)				Highest Tide (feet)		Storm Rainfall (inches)	Remarks P: Property C: Crops
		Low	Time†	Fastest Mile	Time†	Gusts	Time†	#	Time†		
TEXAS	Aug.										
ARANSAS COUNTY											
Aransas Pass	3	28.03stn	1545	NNE 130	1505	SW 180*	1600			6.50	Anemometer blew away at 1505 CST.
Austwell Wild Life	3			N 65*	1400	75*		2.5	1600	1.10	P: $18,000.
Rockport	3	28.84	1522	SE 60	1540	SE 96	1540	5.0	1600	1.85	P: $15,000,000.
ATASCOSA COUNTY											
Charlotte	3			NE 60*	2300	NE 60*	2300			1.78	C: Wind damage to all standing crops.
BEE COUNTY											
Beeville	3			N&NE 60*	1100	NE 75	2100			2.00	P: $500,000. C: $200,000.
NWSED Chase Field	3	29.01	1805	NE 46	1700-1800	E 68	1811			1.44	
Skidmore	3					E 100+*				1.50	P: Heavy.
BRAZORIA COUNTY											
Dow Chem-Freeport	3	29.72	0500	E 22	1130-1500	E 37	1342	4.9	1200	0.85	No damage.
CG Stn Freeport	3	29.76	0630			E 51	0716	4.0	1400	0.25	No damage.
CALHOUN COUNTY											
Point Comfort	3	29.70stn	1400	E 43	1518	E 47	1515	4.5 MLW		0.40	
Port O'Connor	3			ESE 50	1400	ESE 80	1445			1.14	P: $25,000.
Port O'Connor CG Stn	3			NNE 65	1000						P: Boat Sheds: $5,000.
Lavaca Bay Park	3							5.8	1800		
GALVESTON CO.											
Galveston WSO	3	29.83	0400	SE 31	0856	SE 41	0900	3.0		0.37	P: Small; minor damage to piers and small boats.
HARRIS COUNTY											
Baytown	3							5.3	1800	1.20	
Houston WSO IAH	3	29.74stn	1455	E 20	1106	E 38	1105			0.16	Very minor property damage caused by tides in upper Galveston Bay.
JEFFERSON COUNTY											
Port Arthur WSO	3	29.84	0300	SE 23	1206	SE 38	1207	2.5	0630	0.61	No significant damage. Minor flooding in Sabine Pass; water and debris closed highway 87 between Sabine Pass and High Island.
JIM WELLS COUNTY											
Alice	3			NW&WSW 70		SW 80*	1900			3.63	Eye of hurricane passed over Orange Grove about 1930-2000.
Sandia	3					S 160*				2.00	Eye passed Sandia area about 1800. Wind came in sharp gusts.
LA SALLE COUNTY											
Cotulla FAA	3-4	28.86stn	2330	N 36	2310	N 68	2320			2.68	P: Minor.
LIVE OAK COUNTY											
George West	3					SSE 100*	2000-2100			0.81	Eye about 10 mi south of George West.
Three Rivers	3					NE-NW 100*				1.38	
McMULLEN COUNTY											
Tilden	3					NE-E 100*	2100			1.56	Eye of hurricane passed to south of Tilden. U.S. Navy Bombing Station in SW part of county reportedly measured wind speeds in excess of 100 m.p.h. P: $750,000. C: $ 25,000.
Tilden 14-S	3					N 100*				1.87	
NUECES COUNTY											
Corpus Christi											
Corps of Eng.	3	28.30	1600					4.9	1730		
Lipan St. CPL	3	28.36	1600			143	1632				CPL: Central Power and Light Company.
Naval Air Station	3	28.61	1535	SSW 92	1555	SSW 120	1555			8.00*	
Nueces Bay CPL	3	28.05	1630-1700			S 150+	1630-1700				
WSO	3	28.47	1628	SW 125	1628	SW 161	1628			6.38	
Padre Island-Nat'l Seashore	3	29.26	1400	SW 63	1450	SW 82	1450				F420 Anemometer.
Port Aransas CG	3			NNE 104	1433	NNE 127	1433				F420 Anemometer.
Port Aransas Beach	3							9.2			
Port Aransas Jetty	3							9.0	1340		
Mustang Island	3							7.9			
Robstown	3					WSW 180*				7.24	Wind estimate based on fact that oil derrick erected to withstand 175 m.p.h. winds was blown down.
REFUGIO COUNTY											
Austwell	3	29.35	1400-1500	N-E 85*		N-E 85*	0900-1700				Tide 3.0 feet below MLW.
Bayside	3	29.03	1503	E 110	1503	E&SE 140*	1503-1600	4.0	1415-1430		P: $150,000. C: $200,000.
Refugio 3 mi S	3	29.36	1550	NNE 120		NNE 160*				3.10	Highest gust of 142 m.p.h. recorded before standard 4-cup anemome'er blew away. Estimated highest gusts 150-160 m.p.h.
SAN PATRICIO CO.											
Gregory, Reynolds Metal	3	28.12	1550	NNW 128	1520	NNW 138	1515			7.00	Eye lull, 30 minutes 1530-1600. Height of anemometer 80 feet.
Odem	3					N&S 160				0.02	Odem in eye of storm; calm for 15 minutes.
Mathis	3			N 100*		N 150				2.23	
Ingleside	3	27.89									Small private barometer belonging to Percy Kennedy, 612 San Angelo St. compared with Weather Bureau portable precision barometer on 8/7/70.
Portland	3					N&S 160*	1530-1630			2.50	Portland in eye; dead calm for 30 minutes.
Taft	3	28.10	1634							4.0*	P: $5,000,000. C: $500,000. Navy pilot reported a peak gust of 180 m.p.h. while flying in vicinity of Taft.
UVALDE COUNTY											
Uvalde	4	29.40	0100	ESE 45*	0100-0300	ESE 75*	0300			1.17	P: $100,000. C: $250,000.
VAL VERDE CO.											
Amistad Dam	4			E 60	0630	E 80*	0630			1.92	Several trees broken off at ground.
Del Rio WSO	4	29.36	0555	ESE 60	0610	ESE 89	0610			1.17	P: $1,000,000.
VICTORIA COUNTY											
Victoria WSO	3	29.66	1600	ENE 35	1445	E 48	1443			0.08	No damage.
ZAVALA COUNTY											
Crystal City	4			SSE 40*	0200	SSE 60*	0200			2.34	
La Pryor	3-4			NW 100*	2230	110*	0100			2.00	P: Heavy.

*Estimated
#Above mean sea level
†Central Standard Time

major damage occurred to well-constructed hangars and other buildings at the airport (fig. 4), and trailers in an adjacent mobile-home park were almost completely demolished. These high-energy wind bursts produced streaky damage across the city of Corpus Christi with debris from the most heavily damaged structures being carried, in some instances, more than 1,000 yd downwind without evidence of any rotary character associated with the transport. Between these long streaks of major damage, there were areas of only minor damage, confined mostly to trees and ornamentals.

In the areas over which the eye or right semicircle of the storm passed, there were less-pronounced debris patterns. However, in cases where structures were badly ruptured, there was evidence that the damage was caused by winds from the south-southeast to southwest and occurred after the passage of the eye.

The damage due to storm surge was confined mostly to the areas around Port Aransas, Aransas Pass, and Rockport. The highest measured tide values were 9.2 and 9.0 ft that occurred at Port Aransas Beach and Port Aransas jetty, respectively. Even around these areas, the greatest damage appeared to come from southerly winds and was mainly to roofs and second floors of structures. At Port Aransas, many structures had the roof and entire second floor swept away with little evidence of damage to the lower floor other than from rain and sea water.

More attention is given here to the pattern of damage in Celia because it is believed that this is indeed a unique phenomenon deserving further study, regarding both the implications for building codes and protective measures during hurricanes and because of its importance in the understanding of nonsteady-state hurricanes and the distribution of wind patterns. Celia clearly demonstrated that the sustained wind, at least under the present definition, is not the relevant parameter upon which engineering design of structures should be based. The rupture of buildings due to wind forces and the hydrodynamical effect of wind moving over rough objects suggests that the definition of sustained wind needs to be revised to reflect the period of time that a given wind speed must prevail to maximize the hydrodynamical forces that, potentially, may be established on a structure due to the movement of the wind over and about it.

Regarding prediction of the track and the timing of landfall, Celia offered few problems. The average displacement error of all 24-hr forecasts of this storm was only 64 n.mi., which is about 60 percent of the long-term average error for storms in this geographical area.

In summary, Celia was meteorologically a unique hurricane: (1) because of the two periods of very rapid development and (2) because of the very unusual winds in the left semicircle—short-period high energy bursts lasting but a few seconds but exceeding the prevailing sustained wind speed by a factor of 2 to 3 or more.

Fortunately, the city of Corpus Christi and its disaster prevention agencies were well prepared for the action called for in the warnings issued on Celia; and by daybreak on August 3, 10 hr before arrival of the storm center, nearly all preparedness measures were complete, and little more could have been done regardless of the gravity of the emergency with which the city was confronted. The effectiveness of these measures was evident in the low casualty figures. A total of 16 lives were lost due to Celia, including the five in Cuba and five in the immediate Corpus Christi metropolitan area. This is the more spectacular because of the fact that property losses in Celia rose to a record for Texas of $444.9 million with an additional $8.8 million in crop damage. In terms of dollar damage, Celia ranks behind the following hurricanes (in order): Camille (1969), Betsy (1965), Diane (1955), and Carol (1954). Meteorologically however, Celia's intensity, in terms of lowest central pressure, ranks it below such Texas storms as Carla (1961) and Beulah (1967) and at least 10 other storms that affected the U.S. coastline. A summary of meteorological data pertaining to Celia is given in table 1.

TROPICAL STORM DOROTHY, AUGUST 13–23

Dorothy formed from an African seedling disturbance that emerged from the coast on August 13. The storm was named on August 19 about 500 mi east of the Lesser Antilles, upon receipt of a reconnaissance report of 50-kt winds and a 1000-mb (29.53-in.) pressure center.

The storm reached its maximum intensity, with lowest pressure of 996 mb (29.41 in.) and highest winds around 60 kt, as it approached the French West Indies early on the 20th. The center passed over the island of Martinique where a low-pressure reading of 999.7 mb (29.52 in.) and winds of 58 kt with gusts to 86 kt were recorded at the town of Caravelle. Fifty persons were reported dead or missing as a result of floods and landslides caused by heavy rains on Martinique, and there was one fatality on Dominica.

The storm moved under an upper level cold trough in the eastern Caribbean and gradually weakened, dropping below tropical storm force on August 22.

During its entire life including its traverse of the Atlantic as a disturbance, Dorothy followed a remarkably straight west-northwestward track. The average displacement error of all 24-hr forecasts was only 46.3 n.mi., less than half the long-term average.

HURRICANE ELLA, SEPTEMBER 7–13

Ella resulted from a depression that formed initially on a sharp surface trough which extended from San Andres to southern Florida on September 8. The depression formed near Swan Island and headed northwestward, becoming a tropical storm in the Gulf of Mexico after crossing the northeast corner of the Yucatan Peninsula. From this point, with a central pressure of 997 mb (29.44 in.) and 50-kt winds, the storm intensified and accelerated on a westward-curving track across the gulf in response to a warm, upper level anticyclone over the system and a lower tropospheric ridge to the north.

Before the westward course became firmly established, a hurricane watch was issued for the Texas Coast with hurricane warnings in the Brownsville-Port Isabel area and gale warnings northward to Port Aransas. When the center came under surveillance of the Brownsville radar about 24 hr before the time of landfall, it became apparent that Ella would cross the Mexican coast some distance south of the border; and subsequent advices stressed the necessity for precautions along the northeast coast of Mexico.

The hurricane decelerated to 7 kt on its approach to the coast as the ridge to the north eroded, while central pressure continued to decrease, falling to 967 mb (28.55 in.) shortly before landfall with winds increasing to 80 kt. The center moved inland in the LaPesca-Soto la Marina area about daybreak on September 12. Details of the effects of Ella in Mexico are scarce, but a report of wind gusts to 130 kt at LaPesca was received. The Purification and San Fernando Rivers crested above flood stage, but no statistics on casualties or damage are available.

TROPICAL STORM FELICE, SEPTEMBER 11–17

An upper level trough that lingered over the western Bahamas for several days spawned a tropical depression just north of Nassau on September 11. The depression drifted west-southwestward for the next 2 days, passing near Key West and spreading needed rains over southern Florida.

As the system turned west-northwestward in the Gulf, the central pressure fell slowly; and a poorly formed tropical storm developed on September 14. Early on the 15th, with Felice under surveillance of the New Orleans radar, a new center appeared to form somewhat to the north of the previous track. Later examination of the radar films proved inconclusive in regard to this development, due to technical problems and also because of the ill-formed nature of the storm center. Therefore, the official track of Felice is drawn, to close approximation, as a smooth track through this area.

The storm appeared to become better organized as it was tracked south of the Louisiana coast by radars at New Orleans, Lake Charles, and Galveston. This was verified by reconnaissance data that yielded an extrapolated central pressure of 996 mb (29.41 in.) and estimated surface winds of 60 kt.

The center crossed the Texas coast at High Island where the pressure dropped to 998 mb (29.47 in.), and wind gusts of 60 kt were estimated. The highest measured sustained wind was 39 kt at Galveston. The storm weakened rapidly as it moved inland and passed close to Houston. The remnants curved northward, passing near Waco, and dissipated in cooler air over Oklahoma on September 17. Rainfall amounts of about 6 in. occurred near the track over land. Storm damage was insignificant, and there were no casualties reported.

TROPICAL STORM GRETA, SEPTEMBER 15–OCTOBER 5

The season's last named storm and third to form from an African seedling developed near the Bahamas on September 26 from a depression that caused heavy rains and squalls over the Leeward and Virgin Islands and Puerto Rico a few days earlier. Since conditions favored further intensification, Greta posed an immediate threat to southeast Florida and the Florida Keys. Gale warnings were issued for the lower East Coast and upper keys and were later shifted southward to include the lower keys, with a hurricane watch advised from Miami to Key West.

Fortunately, the threatened intensification failed to materialize. On the morning of the 27th, with the storm being monitored by radar at the NHC, the rain bands became disorganized and lost their spiral configuration. Reconnaissance data showed that the central pressure was rising from a minimum of 1005 mb (29.68 in.) in the Florida Straits and winds decreased below gale force as the vortex approached the lower keys. Highest sustained winds dropped from 49 kt at Tavernier on Key Largo to 23 kt as the center passed directly over Key West late on the 27th.

The remnants of Greta, still maintaining a closed wind circulation, curved around a high-pressure area in the Gulf of Mexico and eventually crossed the Mexican coast near Tampico on October 4, with a pressure of 1010 mb (29.83 in.).

3. HYBRID STORMS

During the 1970 season, the use of ATS 3 film loops and information gathered by reconnaissance aircraft from the new standard vortex flight tracks brought into focus the need for recognizing and identifying certain hybrid storm types that, in the past, have either been ignored or grouped with other more commonplace tropical cyclones. These hybrids are the subtropical cyclones with origins normally like those of cold Lows of the Palmén (1949) type which tend to follow meandering tracks westward or northward across the subtropics. Others originate deep in the Tropics and are of the Palmer (1951) type.

Frequently, these storms undergo metamorphoses in which the cold core is gradually transformed from a disturbance that draws mainly upon baroclinic sources of energy to one which draws equally upon baroclinic and latent heat sources. Sometimes, these systems remain "neither fish nor fowl," having neither the typical structure of a tropical cyclone nor of a cold Low, although development continues and winds approach or reach hurricane force. Under such circumstances, cyclones of this type might properly be designated "neuter cyclones" or "neutercanes."[1] Infrequently, the metamorphosis process continues until the primary source of energy is the release of latent heat; and the system acquires the physical organic structure of a tropical storm or hurricane (Simpson 1952, Ramage 1961).

Two neuter cyclones were identified in the Atlantic during the 1970 season. One formed in the same, elongated cold envelope of circulation north of Puerto Rico that had been crossed earlier by the depression which produced record rainfall amounts on the island. The neuter cyclone, first identified as a subtropical system in a bulletin from NHC on October 14, moved slowly northward toward Bermuda, increasing in size and intensity as it approached the island. Reconnaissance data showed that, while winds in the boundary layer had increased nearly to hurricane force at some distance from the pressure center, the mass circulation appeared to be fed mainly by the spiral band structure. As the center approached the island on October 16, a radiosonde released from Bermuda at 1345 GMT indicated winds of 130°/75 kt at 900 mb. The pressure fell to 984.4 mb (29.07 in.) at the U.S. Naval Air Station, Bermuda, at 1800 GMT as the center passed just to the northwest. An anemometer at a 100-ft elevation at the NASA Station Bermuda recorded a maximum reading of 87 kt.

After passing Bermuda, the storm accelerated rapidly northward and was finally swept up into a strong frontal zone as it reached Newfoundland on October 17. While the structure and energetics of this cyclone approached or may have reached that of a hurricane for a short period while it was near Bermuda, it was rapidly swept into a baroclinic environment and again modified. Therefore, it was decided not to include it in the inventory of 1970 tropical storms and hurricanes, even though it apparently acquired some tropical cyclone charactertistics during a portion of its life cycle.

Another neuter cyclone developed from an African seedling disturbance that, after marching across the Atlantic to an area northeast of the Bahamas, intensified as it approached the Cape Hatteras area and moved northeastward toward weather ship *Hotel* (4YH). The ship's soundings at 0000 GMT on August 18 still showed relatively low temperatures through the lower and middle levels as the storm approached, although the surface winds increased to 55 kt with gusts to 65 kt at 0012 GMT and the pressure fell to 1001 mb (29.56 in.) as the storm passed very close to the vessel at 0310 GMT. Further deepening accompanied its rapid movement toward Cape Race, Newfoundland; and ships in the area reported winds approaching hurricane force. The *Transorient* (KHVQ) sustained 60-kt winds with a pressure of 996 mb at 1800 GMT on August 18.

This storm, like the one that passed Bermuda in October, presented the general appearance of a tropical cyclone on satellite pictures during a portion of its existence, but available data were not considered sufficiently conclusive to justify its classification as a tropical storm.

A second type of hybrid storm is that of a "minicyclone," one which has the true characteristics of a hurricane and may have full hurricane-force winds for periods of 1 or 2 days, but with maximum winds occurring at extremely small radii, sometimes no more than 5 n.mi. and gale-force winds extending outward no more than 40 to 60 n.mi. These systems often go undetected as they slip through observational networks without appreciably affecting the surrounding wind or pressure patterns. A circulation system that was initially observed on satellite pictures southwest of the Azores in late October may fit into this category. It appeared as a small, tightly coiled, spiraling cloud pattern with the suggestion of an eye at the center. The *Pretoria* (OYNM) reported winds of 65 kt and a 994-mb (29.34-in.) pressure at 1800 GMT on October 27 near the island of Flores in the Azores. No aircraft data were available from this system, and its thermal structure remains uncertain.

[1] Generically, the term "neuter" as applied here refers to the secondary definition, "intermediate or neutral between two basic categories or conditions," and does not imply gender. This expression was suggested to the senior author by Bundgaard (1970).

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